Tentative Recommendations for Prestressed Rock and Soil Anchors

PREPARED BY AN AD HOC COMMITTEE
of the
PCI POST-TENSIONING COMMITTEE

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TENTATIVE RECOMMENDATIONS FOR PRESTRESSED ROCK AND SOIL ANCHORS

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1. SCOPE

This document has been prepared to provide guidance in the application of permanent and temporary prestressed rock and soil anchors utilizing high strength prestressing steel. It represents the present state of the art and outlines what are considered the most practical procedures for installation of prestressed rock and soil anchors. Typical applications are illustrated in the Appendix.

2. DEFINITIONS

Permanent Anchor: Any prestressed rock or soil anchor for permanent use. Generally more than a 3-year service life.

Temporary Anchor: Any prestressed rock or soil anchor for temporary use. Generally less than a 3-year service life.

Downward Sloped Anchor: Any prestressed anchor which is placed at a slope greater than 5° below the horizontal.

Upward Sloped Anchor: Any prestressed anchor which is placed at a slope greater than 5° above the horizontal.

Horizontal Anchor: Any prestressed anchor which is placed at a slope between ±5° with the horizontal.

Anchor Grout: *(Also known as primary injection)* Portland cement grout that is injected into the anchor hole to provide anchorage at the non-stressing end of the tendon. In case of a sheathed anchor, also included in the grout between the sheath and the anchor hole. Resins are also used as anchor grout. Their properties are not covered by this recommended practice.

Corrosion Protective Filler Injection: *(Also known as secondary injection)* Material that is injected into the anchor hole to cover the stressing length of the prestressed anchor, providing corrosion protection to the high strength steel. This material may be grout or other suitable materials.

Consolidation Grout: Portland cement grout that

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is injected into the hole prior to inserting the tendon to waterproof or otherwise improve the rock surrounding the hole.

Inserting: The physical placement of the anchor tendon in the prepared hole.

Lift-Off Check: Checking the force in the prestressed anchor at any specified time with the use of a hydraulic jack.

Proof Load: Initial prestressing per anchor, representing the proof loading.

Transfer (lock-off) Load: Prestressing force per anchor after the proof loading has been completed and immediately after the force has been transferred from the jack to the anchorage.

Design Load: Prestressing force per anchor after allowance for time dependent losses.

Tendon: The complete assembly consisting of anchorage and prestressing steel with sheathing when required.

Anchorage: The means by which the prestressing force is permanently transmitted from the prestressing steel to the rock or earth.

Prestressing Steel: That element of a post-tensioning tendon which is elongated and anchored to provide the necessary permanent prestressing force.

Coating: Material used to protect against corrosion and/or lubricate the prestressing steel.

Sheathing: Enclosure around the prestressing steel to avoid temporary or permanent bond between the prestressing steel and the surrounding grout.

Coupling: The means by which the prestressing force may be transmitted from one partial-length prestressing tendon to another.

Sheathed Anchor: An anchor in which the stressing length of the high strength steel is encased in a grout-tight sheath. The annulus between the sheath and the periphery of the drilled hole may be grouted together with the anchor grout.

Un-sheathed Anchor: An anchor in which the stressing length of the high strength steel is not encased in a sheathing.

Cohesive Soils: Soils that exhibit plasticity.

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In order to better define a soil as cohesive or

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Generally defined as composed of material more than half of which is smaller than the No. 200 size sieve.

Non Cohesive Soils: Granular material that is generally nonplastic, composed of material more than half of which is larger than the No. 200 size sieve.

3. ROCK ANCHORS

3.1 Description

A prestressed rock anchor is a high strength steel tendon, fitted with a stressing anchorage at one end and a means permitting force transfer to the grout and rock on the other end. The rock anchor tendon is inserted into a prepared hole of suitable length and diameter, fixed to the rock and prestressed to a specified force. The basic components of prestressed rock anchor tendons are the following *(see Fig. 1)*:

1. Prestressing steel which may be a single or a plurality of wires, strands or bars. *(Refer to PCI Guide Specifications for Post-Tensioning Materials.)* The total length of the prestressing tendon is composed of two parts:
   a. Bond length *(socket)*, is the grouted portion of the tendon that transmits the force to the surrounding rock.
   b. Stressing length, which is the part of the tendon free to elongate during stressing.
2. A stressing anchorage is a device which permits the stressing and anchoring of the prestressing steel under load.
3. A fixed anchor is at the opposite end of the tendon than the stressing anchor and is a mechanism which permits the transfer of the induced force to the surrounding grout.
4. Grout and vent pipes and miscellaneous appurtenances required for injecting the anchor grout or corrosion protective filler.

3.2 Design Considerations — Rock Anchors

Rock anchors can be installed in downward or upward positions, however, close to horizontal positions are not recommended because of grouting difficulties

Recommended Bond Stress: The ultimate bond stress values given in the table below are

COMMENTARY

non-cohesive it is necessary to know the percentage of fines and also to know the Atterberg limits of soils containing more than 12 percent fines.

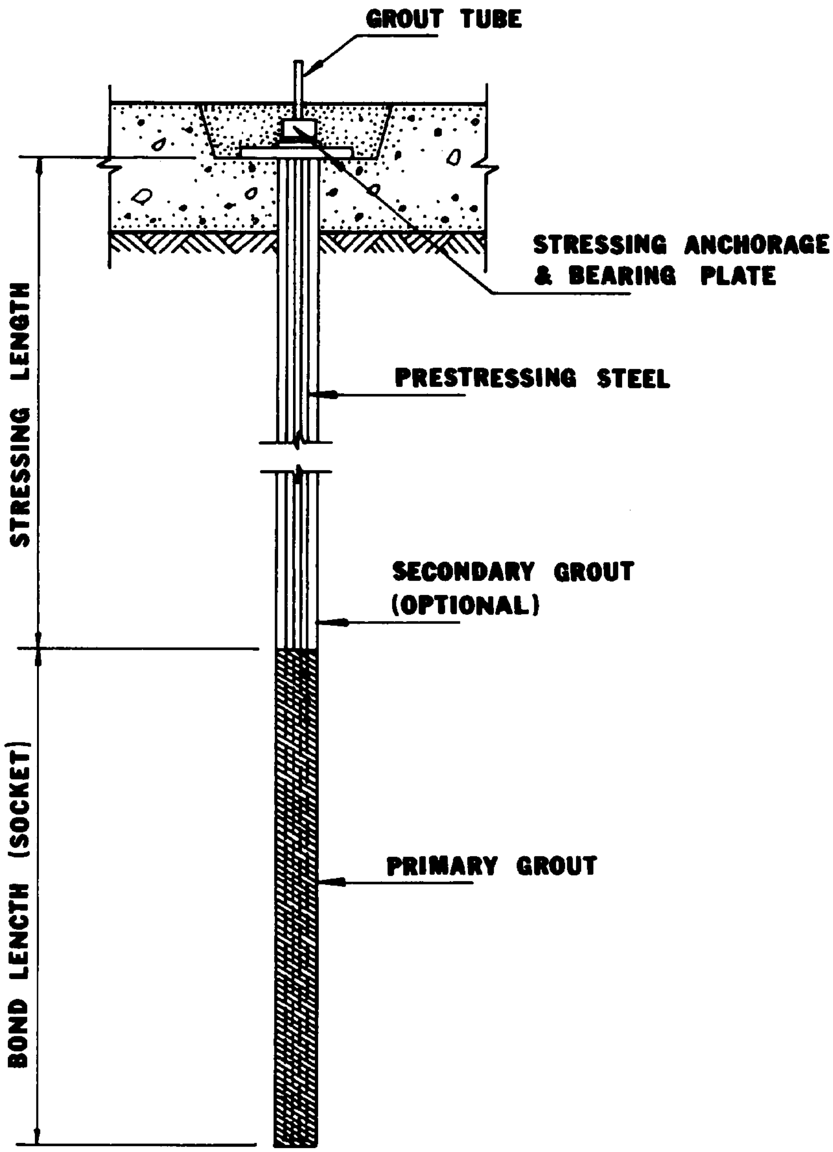

Figure 1 — Rock Anchor

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guide values only. Core drilling to explore the rock quality is an absolute necessity, and core testing together with pull-out tests of test rock anchors are strongly recommended to verify the design assumptions prior to installation of production anchors.

The values presented in the table must be used with a Safety Factor which will depend upon the type of application. The following are suggested methods of obtaining safe working loads:

a. Safety factor applied to the ultimate bond stress obtained from either pull-out tests or bond stress table. Safety factor should range from 1.5 to 2.5.

b. Proof loading of every anchor of not less than 115 percent of its transfer *(lock-off)* force. During the proof loading operation, the prestressing force shall not be more than 80 percent of the guaranteed ultimate tensile strength *(GUTS)* of the high strength steel. The duration of the proof loading is to be specified by the Engineer. Transfer *(lock-off)* the prestressing force at a level of between 50 and 70 percent of its guaranteed ultimate tensile strength. The difference between transfer load and design load shall include allowance for time dependent losses.

The duration of the proof loading is usually up to 15 minutes, in which case, the prestressing force is held by the jack. If longer duration is required, it is recommended to transfer the force to the anchorage and remove the jack.

Typical Bond Stresses for Rock Anchors

Type	Ultimate Bond Stresses Between Rock and Anchor-Grout Plug Sound, Non-decayed
Granite & Basalt	250 PSI – 450 PSI
Dolomitic Limestone	200 PSI – 300 PSI
Soft Limestone*	150 PSI – 220 PSI
Slates & Hard Shales	120 PSI – 200 PSI
Soft Shales*	30 PSI – 120 PSI
Sandstone	120 PSI – 250 PSI
Concrete	200 PSI – 400 PSI

**Bond strength must be confirmed by pullout tests which include time creep tests.*

For small load strand anchors *(such as single strand)* the bond between grout and strand might govern. The bond capacity between grout and strand is about 450 psi.

3.3 Drilling

Holes for anchors should be drilled to a diameter, depth, line, and tolerance as specified by the engineer. The hole shall be drilled so that its

Core drilling, rotary drilling and percussion drilling may be employed as the conditions warrant Core drilling is generally slower and less

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diameter is not more than 1/8 inch smaller than the specified diameter.

3.4 Watertightness

The holes for some or all rock anchors may be tested for watertightness, if specified by the Engineer. When specified, the entire hole shall be tested for watertightness by filling it with water and subjecting it to a pressure of 5 psi. If the leakage rate from the hole over a period of 10 minutes exceeds 0.001 gallons per inch diameter per foot of depth per minute, the hole should be consolidation grouted, redrilled and retested. Should the second watertightness test fail, the entire process should be repeated.

Holes adjacent to a hole being tested for watertightness shall be observed during the test so that any inter-hole connection can be more easily detected.

3.5 Fabrication

3.5.1 Materials

Anchor material shall be in accordance with PCI Guide Specification for Post-Tensioning Materials.

Anchor material shall consist of either single or multiple units of the following:

a. Wires conforming to ASTM Designation A421, "Uncoated Stress-Relieved Wire for Prestressed Concrete."

b. Strand conforming to ASTM Designation A416 "Uncoated Seven-Wire Stress Relieved Strand for Prestressed Concrete."

c. High alloy steel bars, either smooth or deformed.

Stressing achorages shall be capable of developing 95 percent of the guaranteed minimum ultimate tensile strength of the anchor material when tested in an unbonded state.

Mill test reports for each heat or lot of pre-

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economical.

Drilling tolerances are controlled by the size of the drill steel, weight of the drill rig, the method of drilling, and the nature of the ground. Holes can be drilled to an angle tolerance of 3 percent of their planned location.

Holes are water tested to insure limited grout loss for proper anchoring of the tendon, and to insure corrosion protection by limiting loss of either anchor grout or secondary grout. Consistency of consolidation grout depends on the results of the water test. Should the water test indicate a high volume of leakage in the hole, a stiff consolidation grout should be used, such as, a maximum of five gallons water per sack of cement. Should the water test indicate a low volume of leakage, a very lean consolidation grout should be used, such as eight gallons of water per sack of cement.

It is normal practice to redrill a consolidation grouted hole after the grout has had 24 hours to set up.

Payment for consolidation grouting, redrilling and testing should be based on unit prices since these quantities are unpredictable. Typical payment units would be: water tests *(each)*; cement *(CWT)*; redrilling *(lin. ft.)*.

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stressing material used to fabricate tendons shall be submitted if required by the engineer.

3.5.2 Fabrication of Anchors

Anchors shall be either shop fabricated or field fabricated in accordance with approved details, using personnel trained and qualified in this type of work.

Anchors shall be free of dirt, detrimental rust or any other deleterious substance.

Anchors shall be handled and protected prior to installation in such a manner as to avoid corrosion and physical damage thereto.

Anchors may be either sheathed or unsheathed.

The sheathing may consist of tubes surrounding individual anchor elements *(bar, wire or strand)* or a single tube surrounding the elements altogether. A seal shall be provided to prevent the entry of grout into the sheath prior to stressing.

3.6 Insertion and Anchor Grouting

Anchors shall be placed in accordance with the recommendation of the manufacturer.

Anchors shall be securely fastened in place to prevent any movement during grouting.

Grout tubes and vent networks shall be checked with water or compressed air to insure that they are clear.

Care shall be taken to insure that the bond length of the anchor is centrally located in the hole.

If multi-unit tendons are used without a fixed anchorage at the lower end of the tendon, provision should be made for adequate spacing of the tendon elements to achieve proper grout coverage.

Grouting operations shall generally be in accordance with PCI "Recommended Practice for Grouting of Post-Tensioned Prestressed Concrete" and in accordance with the recommendations of the manufacturer.

Primary grout of the proper consistency shall be pumped into the anchor hole through a grout pipe provided for that purpose until the hole is filled to the top of the anchorage zone. The grout shall always be injected at the lowest point of the bond length.

Provisions shall be made for determining the level of the top of the primary grout to assure adequate anchorage.

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A light coating of rust on the anchor material is normal and will not affect the ability of the anchor to perform its function. Heavy corrosion or pitting should be cause for rejection of the anchor.

The sheathing material can be either steel, plastic or any other material non-detrimental to the high strength prestressing steel.

Centering devices are normally provided at about 10 ft. centers throughout the bond length.

It should be recognized that water separation or bleed creates a layer of water at the top of any grouting stage. For strand tendons where bleed is more pronounced, bleed water could be over 6 percent of the vertical height of the tendon. Chemical additives are available that will control the bleed. Collodial *(high energy)* grout mixers will reduce this phenomenon. In the case of two stage grouting, it is normal procedure to fill the void caused by bleed water at the top of the second stage by regrouting after the second stage grout has set.

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After grouting, the tendon shall remain undisturbed until the necessary strength has been obtained.

The following data concerning the grouting operation shall be recorded:

- Type of Mixer
- Water/Cement Ratio
- Types of Additives
- Grout Pressure
- Type of Cement
- Strength Test Samples
- Volume of first and second stage grout

3.7 Stressing

Stressing shall generally be accomplished in accordance with "PCI Manual for Quality Control for Plants and Production of Precast Prestressed Concrete Products."

The anchor shall be first stressed to an initial load of about 10 percent of the test load, which is the starting point for elongation measurements.

Immediately thereafter, the anchor shall be stressed to the proof load and elongation is to be recorded. The magnitude of the proof load is to be determined by the engineer. If measured and calculated elongations disagree by more than 10 percent, an investigation shall be made to determine the source of the discrepancy.

When the above requirements are met, the anchor force shall be lowered and anchored at the transfer load. This load may be verified by a lift-off test and recorded, if required by the Engineer.

3.8 Testing

The stressing anchorages shall be capable of lift-off during the period of installation, in order to check the force.

The lift-off test, if any, is to be specified by the engineer. Allowances shall be made for time dependent losses when comparing the lift-off force with the previous transfer load.

3.9 Corrosion Protection

Prestressed rock anchors shall be protected against corrosion by procedures suitable for the

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In the case of sheathed anchors, the first stage grouting covers the full length of the anchor between the sheathing and the periphery of the hole, and may fill the space between the sheathing and tendon throughout the bond length. Second stage grouting may be used to fill the space between the sheathing and the tendon throughout the stressing length or throughout the entire anchor length.

For sheathed anchors, consideration should be given to force transfer through the grout in the annulus around the stressing length.

Stressing is normally carried out seven days after grouting for Type I or Type II cements and three days after grouting for Type III cement. At these times, grout with a water-cement ratio of 0.45 will have a compressive strength of about 3500 psi.

Movements of the bearing plate in excess of ½ inch shall be taken into consideration in comparing measured and theoretical elongations. For temporary rock anchors, elongation measurements are not usually required.

Usually, the proof load is specified as 115 percent to 150 percent of the transfer load. The proof loading of anchors is part of the stressing operation and occurs just prior to load transfer.

The lift-off, if required, is usually done on a random basis. The engineer is to determine the percentage of tendons tested. Meaningful lift-offs can be taken as soon as 24 hrs. after the anchor is stressed. It is poor practice to require that the jack be left on an anchor since the jack bleeds off and the results are incorrect.

For most rock anchor applications, the primary time dependent loss is steel relaxation which can be as much as 3 percent of the transfer load in seven days depending on the type of steel. More exact values can be obtained from the rock anchor supplier.

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intended service life.

3.9.1 Temporary Rock Anchors

Corrosion protection provided for temporary anchors shall be based on the intended service life of the anchor, and on the corrosion potential of the environment in which the anchor is to be installed. For wedge-type post-tensioning systems, protection shall be applied to the anchor head and wedge holes prior to insertion of wedges and stressing of tendons. Corrosion protection of temporary anchors shall be inspected and maintained throughout the service life of the anchor.

Appropriate spacers shall be provided to center the tendon in the hole throughout the bond length to insure adequate cover.

3.9.2 Permanent Rock Anchors

Permanent rock anchors shall be provided with protective corrosions seals over their entire length.

For tendons utilizing sheathing over the stressing length, the annulus between sheathing and tendon in the stressing length of the tendon shall be protected with a preplaced grease, powder corrosiion inhibitor or grout. A grout plug shall be provided to seal the end of the sheathing adjacent to the bond length. Grout shall be applied from the bottom of the anchor hole covering bond length and the annulus between sheathing and rock in the stressing length in one continuous operation.

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When in rock where there is no apparent danger of corrosive attacks, temporary anchors with a service life up to 3 years are sometimes installed with no corrosion protection along the stressing length. However, normal practice for temporary anchors requires use of a ferrous metal or suitable plastic sheathing covering the stressing length to keep the prestressing steel dry and protect it from contact with the surrounding rock. A watertight seal should be provided between the sheathing and the grout in the bond length on one end and between the sheathing and anchorage device at the other end. The annular space between tendon and sheathing may contain preplaced grease or powder corrosion inhibitors. Asphaltic painting or grease corrosion protection of anchorage hardware is recommended. For wedge-type post-tensioning systems, a small amount of movement or travel of the wedges is required to develop force in the tendon above the transfer load. To develop the full tendon capacity, the required wedge movement may vary from approximately 1/32 inch to 1/8 inch depending on the wedge type and the transfer load level. Therefore, to assure that the tendons have capacity to sustain unanticipated loads substantially in excess of the transfer load, it is important that corrosion protection of anchorage hardware be provided and maintained.

Centering devices are normally provided at about 10 ft. centers throughout the bond length.

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Permanent rock anchors utilizing a two stage grout system may be fabricated without the use of sheathing above the bond length. Grout shall be injected from the bottom of the anchor to the top of the bond length. Grout quantity shall be continuously monitored. Secondary grouting shall be applied to the stressing length after stressing and any required stress monitoring are complete and accepted.

Special attention shall be given to assure corrosion protection of the tendon at the connection to the anchorage hardware. The anchorage hardware shall be protected by embedment in concrete or other suitable material.

4. SOIL ANCHORS

4.1 Description

A prestressed soil anchor is a high strength steel tendon, fitted with a stressing anchor at one end and an anchor device permitting force transfer to the soil on the other end. These anchors, which are used in clay, sand or other granular soils, are inserted into a prepared hole or driven into the soil. Concrete is gravity placed to form an anchorage, or grout is injected under pressure to form a bulb of grout to anchor the tendon. Pressure bulb soil anchors are usually equipped with a casing, which is withdrawn during the grouting operation. Subsequent to placement of anchor grout, the soil anchor is stressed and anchored at a specified force.

Soil anchors may be classified as follows depending on their use in cohesive or noncohesive soils.

Soil anchors in noncohesive material are generally pressure grouted *(See Fig. 2)*. They may be installed by two procedures:

1. Auger drilled - using hollow stem continuous flight augers normally of 6" to 10" diameter, the tendon is placed through the hollow stem of the auger before or after drilling is completed. Concrete or grout is then pumped under pressure through the hollow stem and the auger is withdrawn as the grout fills the hole.
2. Drilled or Driven Casing Pressure Grouted. In this type of anchor a 3" to 6" diameter casing is either drilled or driven into the ground to the final depth. The casing is then cleaned

A "lost point" on the bottom end of the casing is used in this method. The point remains in the ground during and after casing withdrawal.

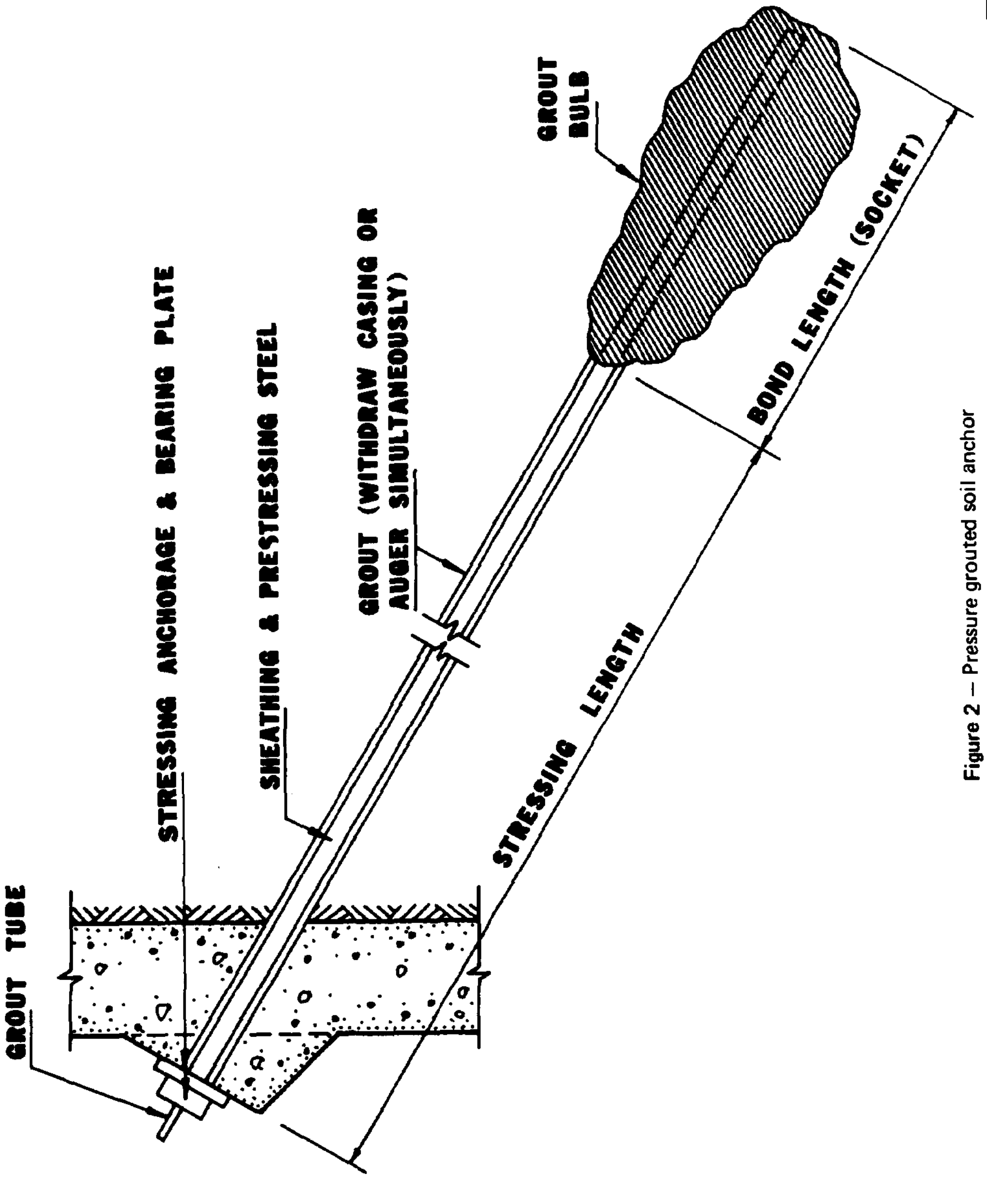

Figure 2 — Pressure grouted soil anchor

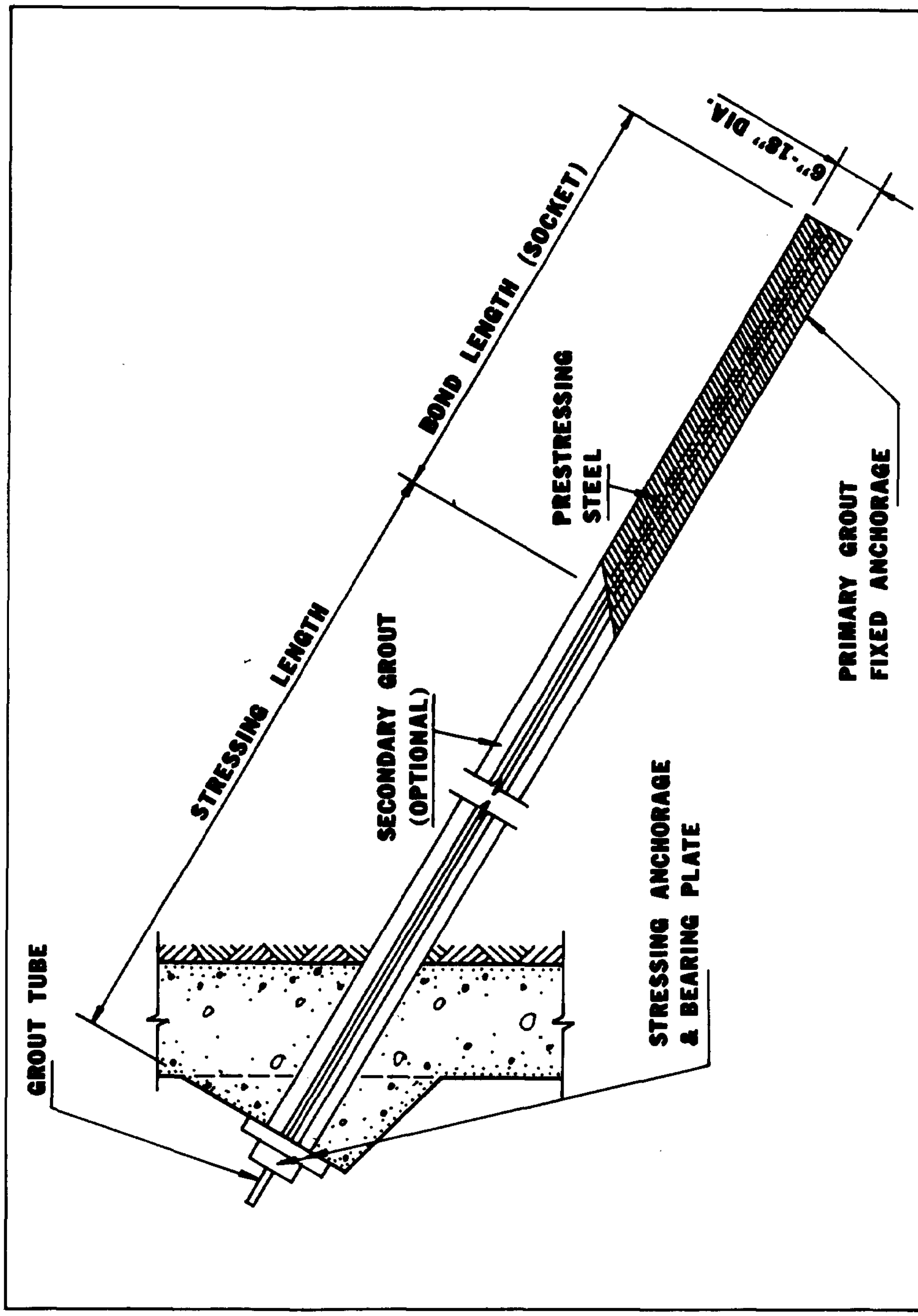

Figure 3 — Augered soil anchor

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out and the tendon inserted. The anchor is then pressure grouted over the anchoring zone as the casing is withdrawn. Grout pressures used vary from 50 to 200 psi.

Soil anchors in cohesive soils are generally of the following types:

1. Auger Drilled *(See Fig. 3)* - using either continuous flight augers or short augers on a Kelly Bar type of machine. These anchors differ from those drilled in cohesionless soil only in the way they are grouted. The auger is withdrawn before grouting, and pressure grouting is not used.
2. Belled Type Anchors *(See Fig. 4)* - Drilled either by a Kelly Bar type machine using augers and a standard caisson belling bucket or the drilled casing method which employs a small air or mechanically activated underreamer. The cuttings are removed by air or water flushing. Belled anchors rely on the bearing of the underream cones against the soil for resistance to pullout.

4.2 Design Considerations

The design of soil anchors is largely dependent on the soil conditions and upon the type of anchor used. Use of test anchors to determine the necessary bond length is strongly recommended for augered anchors and is essential for pressure bulb type soil anchors.

Minimum stressing lengths of 20 to 25 ft. are recommended.

4.3 Drilling

4.3.1 Augered holes

Augered holes may vary from 6 inches to 24 inches in diameter and lengths may be as much as 100 feet. Some augers have attachments which permit belling or enlarging the bottom of the hole. More than one bell may be provided in cohesive soils.

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For large diameter holes, augered anchor bond stresses in the bond length are normally about 10 psi although there can be a wide variation in this figure. It is not practical to give typical bond stress values for pressure bulb type soil anchors. Pressure bulb anchors develop the tendon force partially through bond and partially through bearing of the bulb of the soil. The response of soils to the pressure grouting varies widely, and, for this reason, field anchor tests are necessary to properly design pressure bulb anchors.

The minimum stressing lengths recommended are necessary so that small movements of the stressing anchor will not result in large changes in load.

Augered holes are the fastest method of drilling a soil anchor.

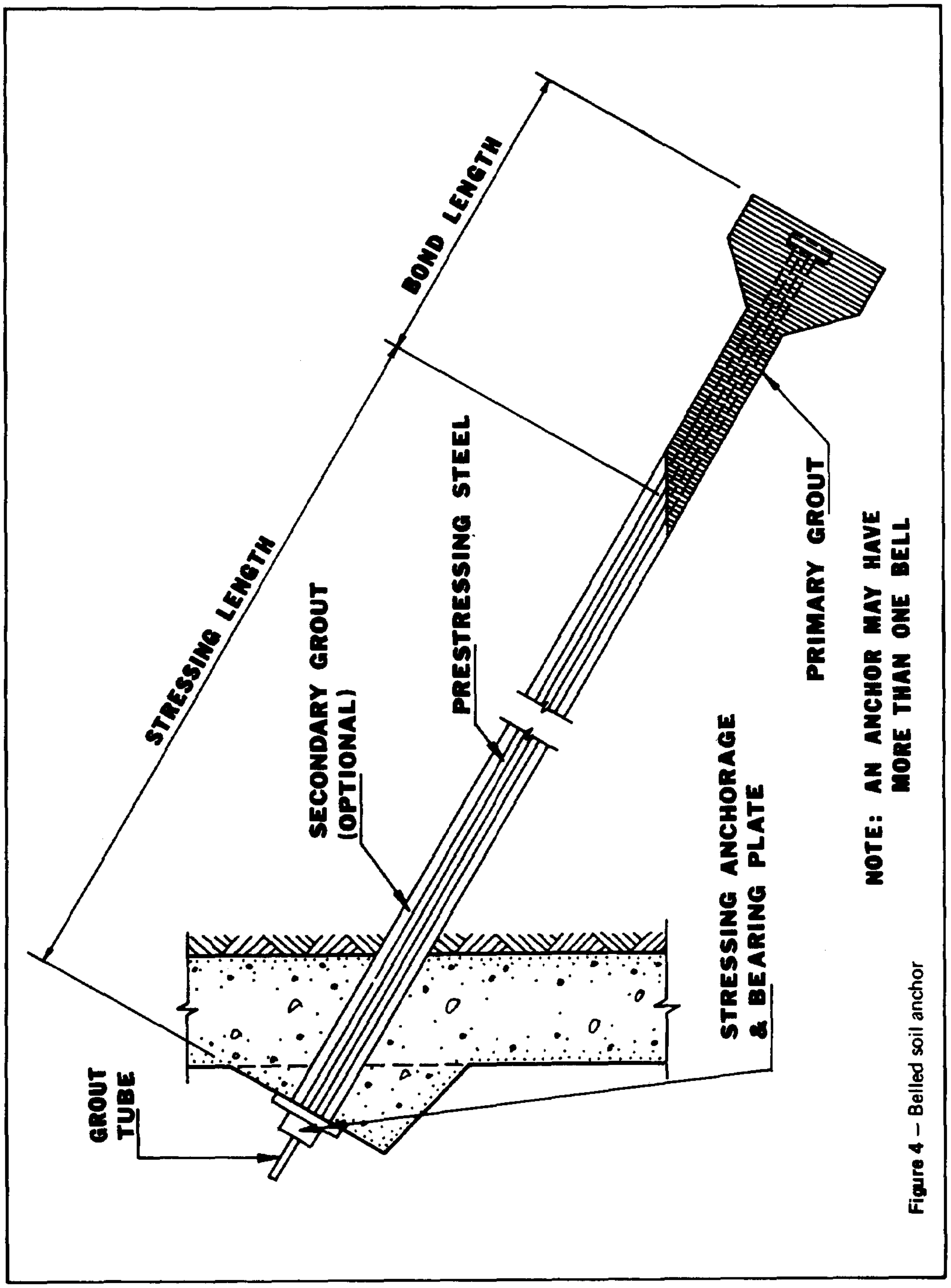

Figure 4 – Belled soil anchor

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4.3.2 Pressure Grouted Anchors

Pressure grouted anchors are installed by either ramming a casing with a detachable point using an air track, or by augering a small hole with a hollow stem continuous flight auger.

4.4 Fabrication

4.4.1 Materials

Soil anchor materials shall conform to the requirements of Section 3.4.1 Materials for prestressed rock anchors.

4.4.2 Fabrication of Anchors

Anchors shall be either shop fabricated or field fabricated in accordance with approved details, using personnel trained and qualified in this type of work.

Anchors shall be free of dirt, detrimental rust or any other deleterious substance. Anchors shall be handled and protected prior to installation in such a manner as to avoid corrosion and physical damage.

Anchors may be either sheathed or unsheathed.

4.5 Insertion and Anchor Grouting

4.5.1 Augered or Belled Anchors

Soil anchors are manually inserted in augered holes. Concrete or grout is pumped or gravity placed into the bond length of the anchor.

4.5.2 Pressure Grouted Anchors

4.5.2.1 Rammed Anchors

The prestressing tendon is inserted in the casing and driven to its final position with the casing, or the tendon may be inserted after the casing is driven. Grout, under pressure, is pumped into the sealed casing as the casing is withdrawn from the hole by means of hydraulic jacks. After the casing has been withdrawn from the bond length, pressure grouting is discontinued and the casing may be withdrawn.

4.5.2.2 Augered Pressure Anchors

A small diameter continuous flight auger is used to drill the hole. The procedure for installing this type of anchor is exactly the same as the

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Ramming is usually only employed in fairly loose sands and gravels.

A light coating of rust on the anchor material is normal and will not affect the ability of the anchor to perform its function. Heavy corrosion or pitting should be cause for rejection of the anchor.

Spacers are normally provided at about 5 ft. centers in the bond length of augered anchors.

The sheathing material can be either steel, plastic or any other material non-detrimental to the prestressing steel.

It is common practice to withdraw the casing and continue pumping grout at pressures high enough to result in a grout requirement of one bag of cement per foot of hole. However, the grout requirement depends greatly on the hole diameter, and the permeability and density of the soil.

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driven anchor described above with the exception that the auger is always completely withdrawn.

4.5.2.3 Upward Sloped Soil Anchors

Pressure type soil anchors may be installed on upward slopes.

4.6 Stressing

Stressing shall generally be accomplished in accordance with "PCI Manual for Quality Control for Plants and Production of Precast Prestressed Concrete Products."

4.7 Testing

Soil anchors in cohesive soils normally require more testing than rock anchors since cohesive soils may creep under sustained load. Continuous monitoring systems may be employed when specified by the Engineer.

4.8 Corrosion Protection

Measures to provide corrosion protection for soil anchors vary depending on whether the anchor is intended for temporary or permanent use. In both cases, protective measures are similar to those for prestressed rock anchors presented in Sections 3.9.1 and 3.9.2.

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Stressing is normally carried out seven days after grouting for Type I or Type II cements, and three days after grouting for Type III cement. At these times, grout with a water-cement ratio of 0.45 will have a compressive strength of about 3500 psi.

Soil anchors are normally stressed to 15 to 50 percent above design load, held at that load for 5 or 10 minutes, and then relaxed and anchored at the design load.

Lift-off tests are sometimes performed on selected anchors; these may be of 8-hour duration in the case of granular soils, but 24-hour duration may be called for on anchors in cohesive soils

The average monitoring system consists of a load cell placed behind the stressing anchorage. This load cell has SR4 strain gauges installed on it, and the results can be directly read on a Wheatstone bridge. A separate payment item should be set up for monitoring.

APPENDIX

TYPICAL APPLICATIONS OF PRESTRESSED ROCK AND SOIL ANCHORS

A.1 INTRODUCTION

The purpose of this appendix is to illustrate typical applications of prestressed rock and soil anchors as they have been used to date in the United States and Canada. The first application of a prestressed anchor dates back to 1935 when the late Andre Coyne, a French engineer, used prestressed anchors to stabilize the Cheurfas Dam in Algeria. Until recently, the 1100 ton anchors used in the Cheurfas Dam were the largest ever installed in a structure. This project generated a number of new systems and applications in Europe. However, the widespread use of prestressed rock and soil anchors is a relatively recent development in North America.

The examples presented below are representative of the techniques used most often in present-day construction. Additional applications and variations of the projects illustrated have been used, and no doubt more will be developed as engineers become more familiar with this construction technique.

A.2 BUILDING EXCAVATIONS

Rock and soil anchors make possible the effective use of modern excavation methods by eliminating internal bracing and allowing free movement of the excavating equipment. Prestressed tie-backs also make it possible to reduce or eliminate settlements of structures adjacent to the excavation because wall movements or deflections can be minimized. Many different wall types have been anchored with prestressed rock and soil anchors including: Steel H piles with wooden lagging; steel sheet piles; drilled concrete shafts; and, slurry walls. Tie-back applications for building excavations are illustrated in Figs. A-1, A-2, A-3, and A-4.

A.3 RETAINING WALLS AND REVETMENTS

The rather unusual structure in San Francisco shown in Figs. A-5 and A-6 is one of many walls with post-tensioned tie-backs built under plans developed by the Bridge Department of the California Division of Highways. This retaining wall is a series of twenty-two thin horizontal arch sections supporting the earth between inclined buttresses that are anchored into the earth and rock by prestressed anchors. The wall has a maximum height of about 60 ft. and was built in a series of 12 ft. increments from the top down as excavation proceeded. The precast concrete blocks used for the inclined buttresses were anchored by 100 kip soil anchors with length varying from 30 to 45 ft. The post-tensioned wall was selected to minimize earth movements which might cause damage to the property on top of the wall. Also, because no footing was required, it was unnecessary to disturb or shore the property at the top of the wall during construction.

Fig. A-7 shows details of a retaining wall built on Interstate Highway I-96 in Detroit. The wall was built in extremely poor clay and rock anchors were used to minimize potential soil movement effects on the wall and the I-96 freeway. Figs. A-8 through A-10 illustrate installation and stressing of the 1575 kip rock anchors which utilized 54 half inch diameter 270k strands.

Fig. A-11 shows details of a retaining wall in San Diego which utilizes five foot diameter concrete "soldier beams" and soil anchors at 10 ft. centers to minimize potential soil movement and possible damage to the adjacent apartment building. The vertical beams and tie-backs were built first and then the concrete wall was built in front of the vertical beams. The 90 kip soil anchors were placed in a 10 inch diameter hole and varied in length from 24 to 31 ft.

Over a period of years, apparently stable rock faces can deteriorate by weathering. This can be prevented by prestressing a retaining wall against the rock using rock anchors as shown schematically in Feg. A-12. Fig. A-13 shows a Swiss application of a revetment of this type. In some cases, the concrete retaining wall may be replaced by a direct application of shot-crete to the rock face. The rock anchors are used in the same fashion.

A.4 SLOPE STABILITY

The availability of prestressed rock anchors installed as illustrated in Fig. A-14 often provide an economical means of stabilizing rock slopes. The other tools available to cope with stability problems are huge gravity retaining walls or cuts of slope angle to coincidde with the mechanical properties of the rock. Both of these solutions require large excavations.

The rock slope at Libby Dam in Montana shown in Feb. A-15 had three huge faults, minor, flat, and approximately 30° downward. After the cut section was excavated for highway construction, the upper bed of stratum slid down along the first fault, leaving an uneven rock surface exposed. The second bed then became dangerously unstable. A retaining structure of any kind would not have been practical or feasible. After extensive rock mechanics investigation, it was determined that an effective prestressing force of 18,000 kips, making an approximate 60% angle with the fault, would stabilize the surface of the rock. This force would tie the unstable portion to the main rock mass of the slope as well as increase the frictional forces in the failure plane. Fig. A-16 shows installation of the 200 kip anchors, and Fig. A-17 shows the concrete cover placed over the stressing anchorages to provide complete corrosion protection.

A.5 STABILIZATION OF UNDERGROUND EXCAVATION

Stabilization of tunnel excavations in rock with prestressed rock anchors is distinguished from the more conventional lining methods by the fact that the prestressing creates an active arch in the rock making it act as its own structural support. This technique avoids costly bracing and shoring and increases the speed of excavation.

Fig. A-18 shows drilling preparatory to placement of a prestressed rock anchor in a tunnel.

A.6 DAM STABILIZATION

Requirements for increased capacity or improved safety of concrete dams can often be facilitated by use of prestressed rock anchors. This method is commonly used when an existing dam is to be increased in height, and prestressed rock anchors may also be helpful in restoring the water-tightness of cracked dams or locks by compressing the structure and closing the cracks.

Fig. A-19 shows drilling in progress for installation of prestressed rock anchors on the Ocoee Dam in Tennessee. Fig. A-20 shows installation of the 170 wire tendons used to provide improved stability of the dam.

A.7 ANCHORAGE AGAINST UPWARD WATER PRESSURE

When basin-shaped structures located in an area of high ground-water are in an unloaded state, danger of uplift exists. A possible solution to this problem is mass concrete, but the cost of the extra excavation and material sometimes renders this method too expensive. Rock anchors may often be used in such a situation with a substantial reduction in cost.

A.8 ANCHORAGE OF FIXED POINTS

Suspension bridges, cableways, locations where pressure pipes change direction, pylons or other structures can often be advantageously anchored with rock or soil anchors. Most important here is the fact that the transfer of the anchoring force can be effected in a stable load-carrying ground or rock zone.

Fig. A-21 shows the Hudson Hope Suspension Bridge in British Columbia. Anchorage of the main suspension cables was achieved by use of the prestressed anchor details shown in Fig. A-22. In the case of the Hudson Hope Bridge, the post-tensioned anchors were preferred because the anchor plates would remain virtually motionless under all load conditions, and no anchor load would be transferred to the surface rock which was normally fissured or water bearing. In some applications, post-tensioned suspension bridge anchorages have shown an economic advantage over alternate methods, and, in general post-tensioned anchorages will provide a more accurate and constant zero point for connection of the cable strands.

The problem of supporting concentrated forces is often encountered in all types of underground construction. Rock anchors allow the transfer of these loads directly to the rock without the necessity of providing a heavier lining. Typical examples are crane rails, derricks and structural support beams.

In bridges where overturning forces due to earthquake or wind are large, post-tensioned rock anchors may be a more economical way to provide the necessary anchorage. The Pine Valley Creek Bridge near San Diego shown under construction in Fig. A-23 has piers ranging to 340 ft. in height, and stability under earthquake forces is obtained through use of post-tensioned rock anchors connecting the footing to the underlying rock mass. In this case, the rock anchors were considered more economical than additional excavation and use of large gravity-type concrete foundations.

A.9 MISCELLANEOUS APPLICATIONS

Rock or soil anchors may cut time and cost when used for pile testing, and often add safety and flexibility. Loads are applied to the pile through a beam loaded by prestressed anchors, thus eliminating the necessity of large testing weights. The anchor will give precise and continuous indications of pile movement as well as allow measurement of applied load.

Settlements of structures in compressible ground can be avoided by extending their foundations to a solid stratum, but sometimes this is not practical. In these cases, settlement can be induced prior to construction by loading the foundations with rock or soil anchors. The anchorage forces, of course, would be of the same magnitude as the future design load and must act on the stratum which causes settlement.

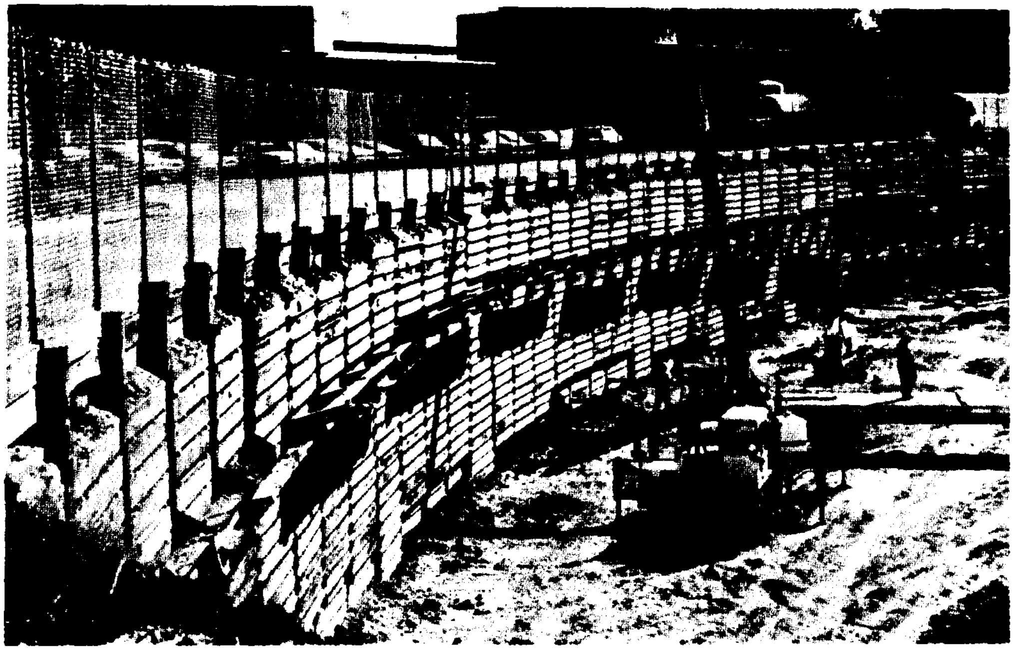

Figure A-1 — Prestressed Soil Anchors used to tie-back a wall of soldier piles with wooden lagging.

Figure A-2 — Drilled concrete shafts supported by three levels of tie-backs and walers.

Figure A-3 – Concrete slurry wall. Top level of anchors utilize steel walers to transmit anchor force to wall; bottom layer of anchors use concrete pedestals.

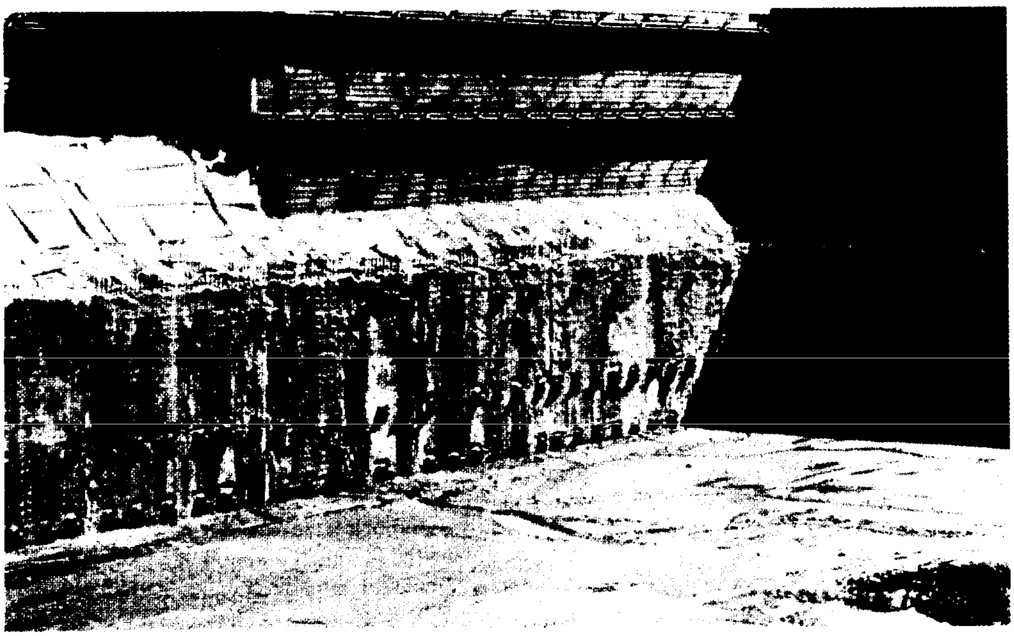

Figure A-4 – Upper wall of soldier piles and wooden lagging braced by two layers of tie-backs with steel walers. Lower level of reinforced slurry wall construction with multiple levels of tie-backs.

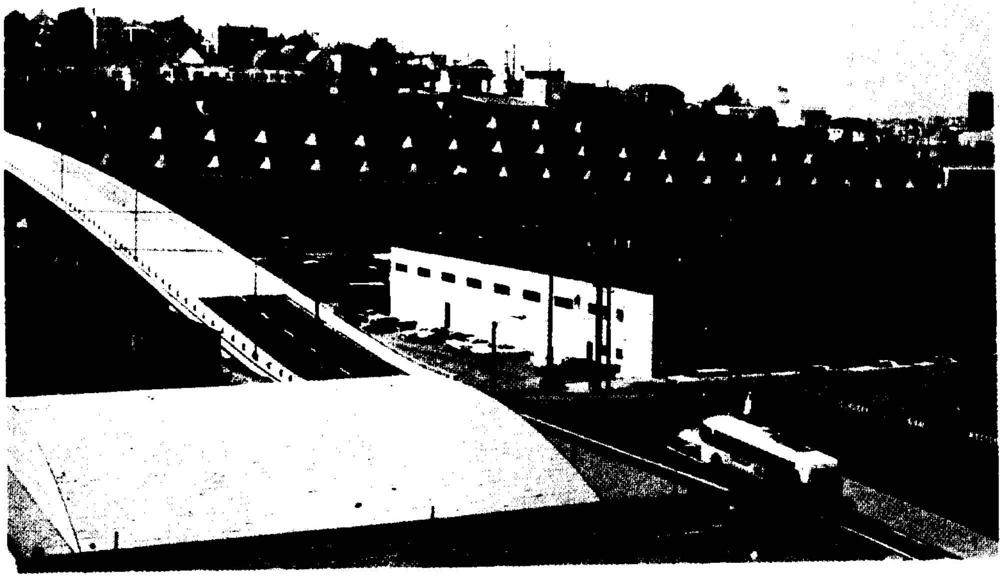

Figure A-5 — Protrero Hill retaining wall, San Francisco

Figure A-6 — Protrero Hill retaining wall, San Francisco

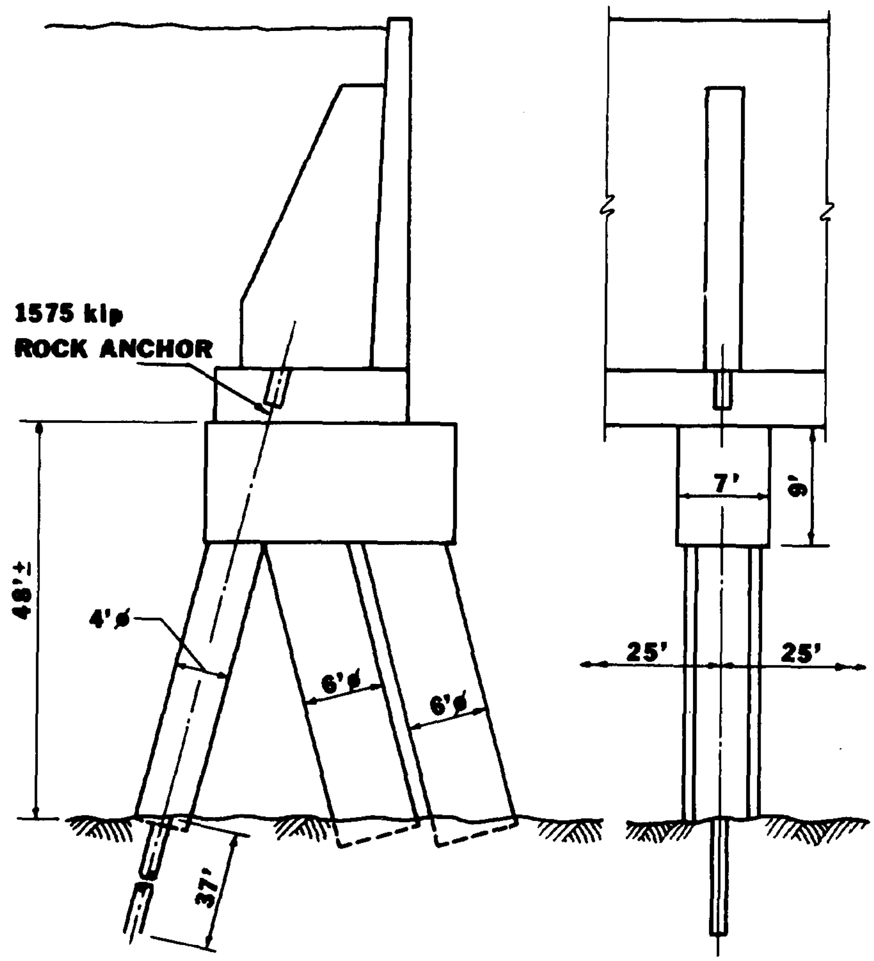

Figure A-7 — Retaining wall details, Interstate Highway I-96, Detroit

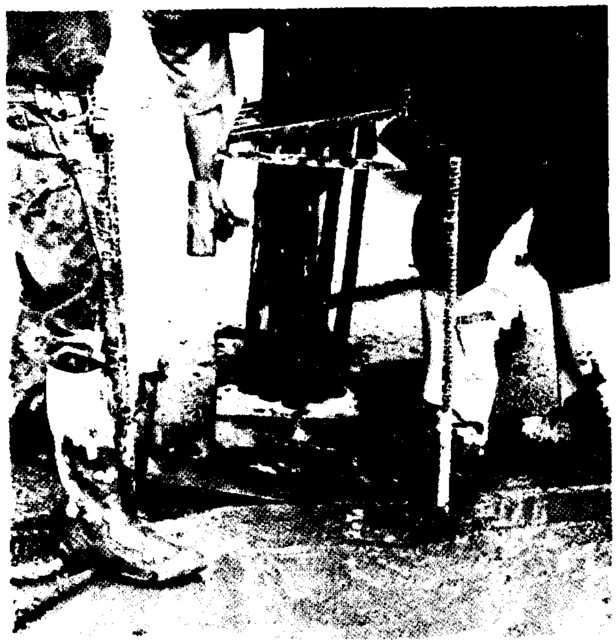

Figure A-9 — Placing wedge anchor plate, Interstate Highway I-96 retaining wall, Detroit

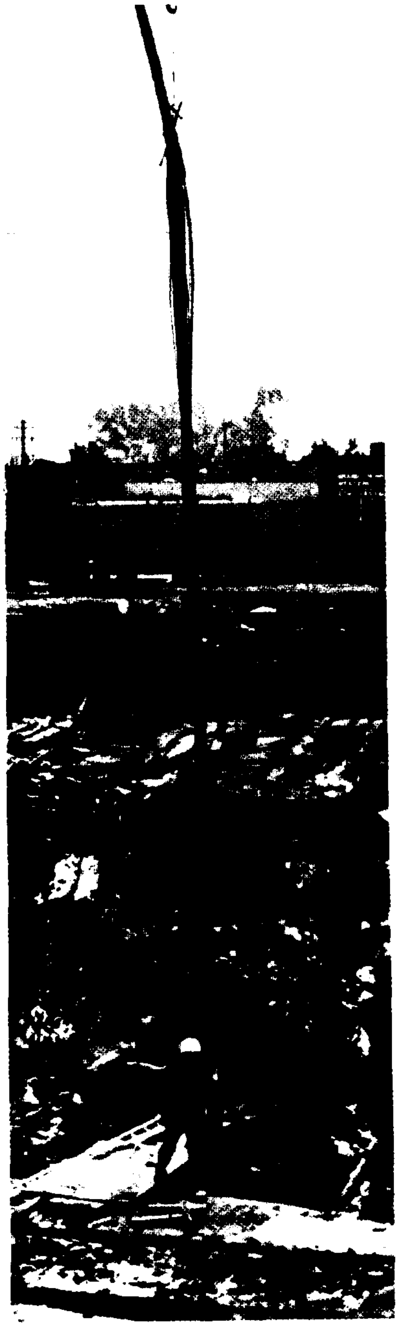

Figure A-8 — Tendon installation, Interstate Highway I-96 retaining wall, Detroit

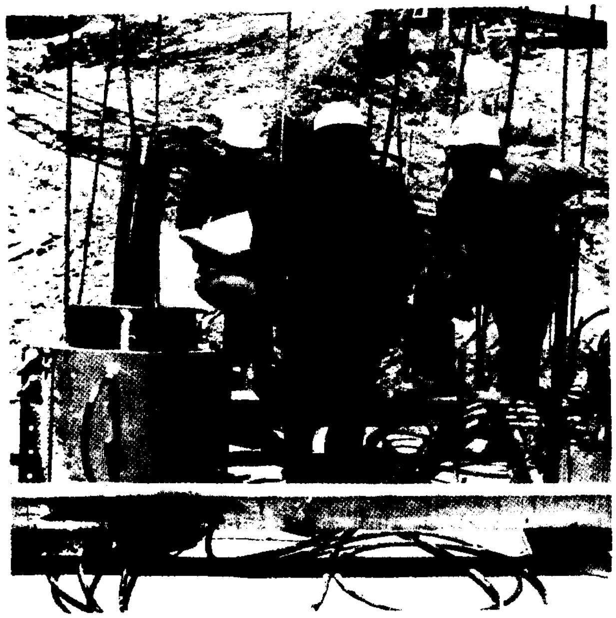

Figure A-10 — Stressing 54 strand tendon, Interstate Highway I-96 retaining wall, Detroit

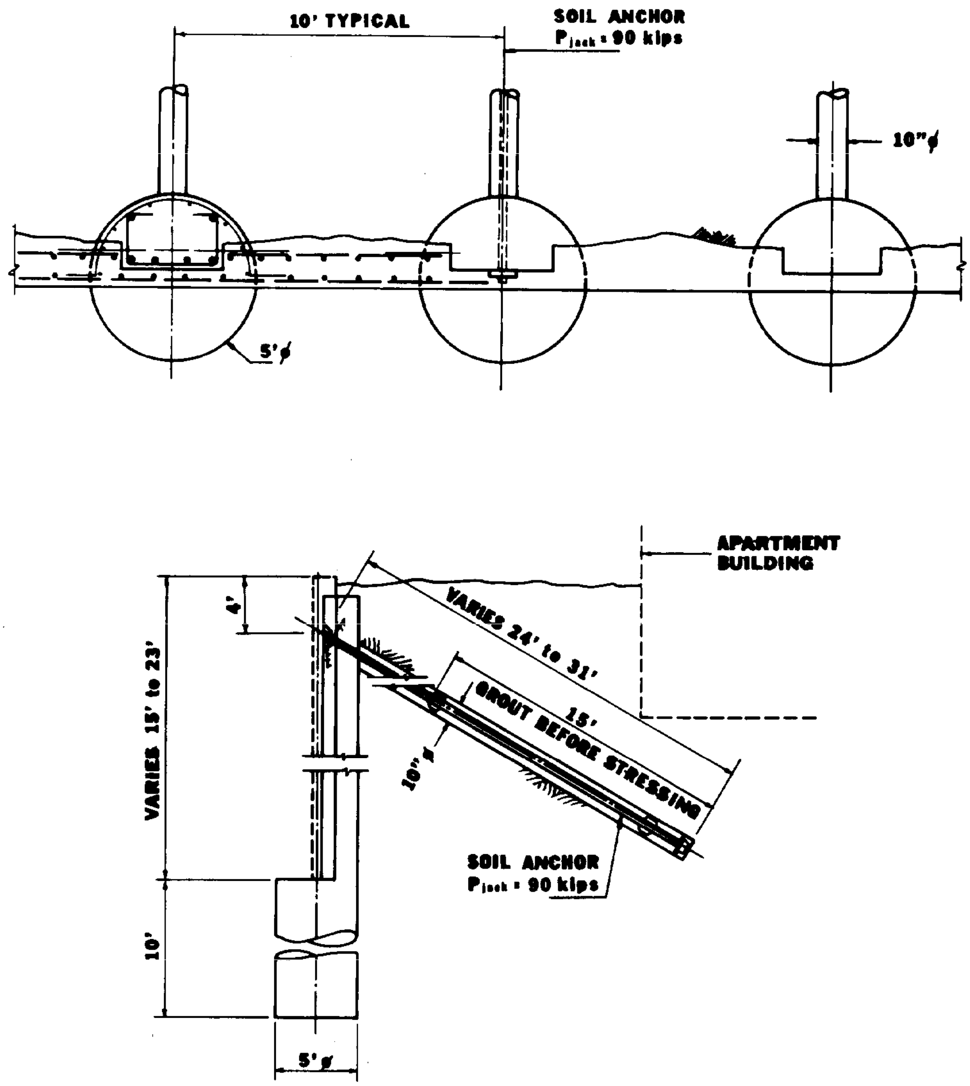

Figure A-11 – San Diego retaining wall details

Figure A-12 – Rock face revetment concept with rock anchors

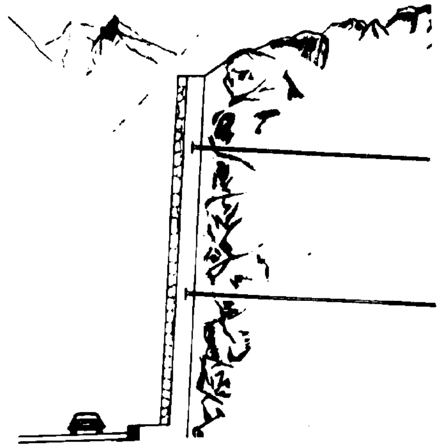

Figure A-13 – Rock face revetment, Switzerland

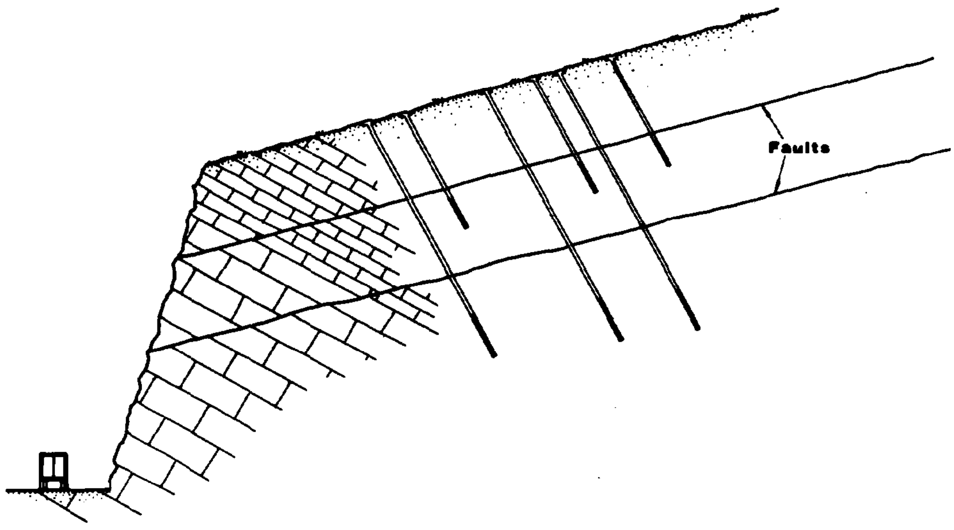

Figure A-14 — Concept of slope stabilization with rock anchors

Figure A-15 — Rock slopes at Libby Dam, Montana

Figure A-16 – Installation of 200 kip anchors, Libby Dam, Montana

Figure A-17 – Concrete cover over stressing anchorages, Libby Dam, Montana

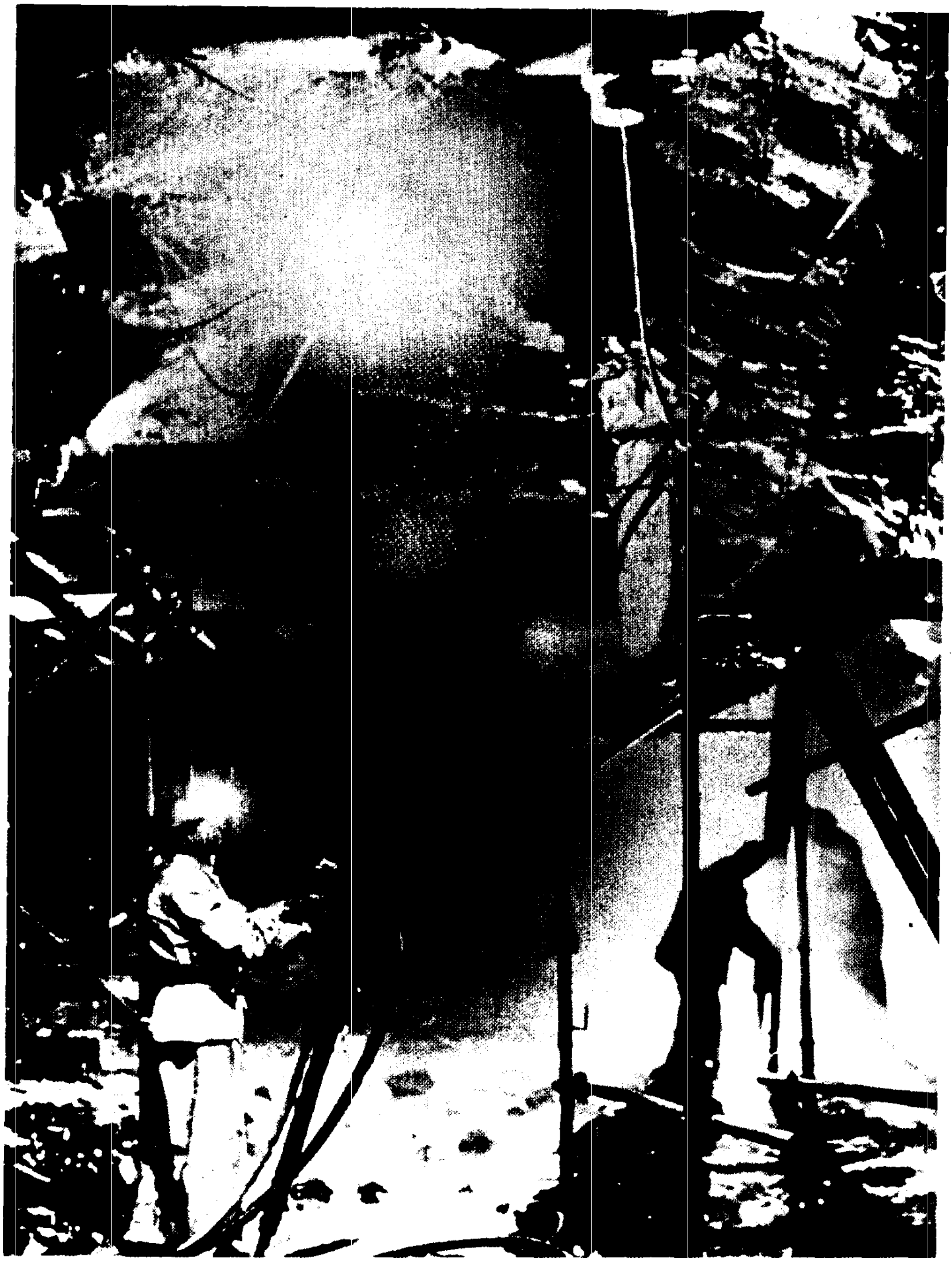

Figure A-18 – Drilling for rock anchors in tunnel excavation

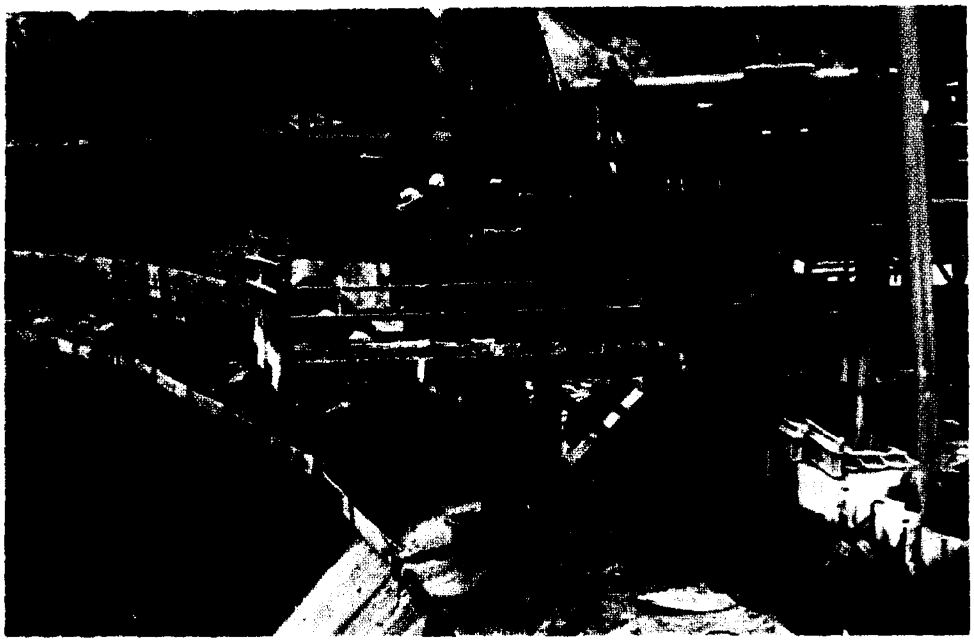

Figure A-19 — Drilling for rock anchor installation, Ocoee Dam, Tennessee

Figure A-20 — Installation of rock anchors, Ocoee Dam, Tennessee

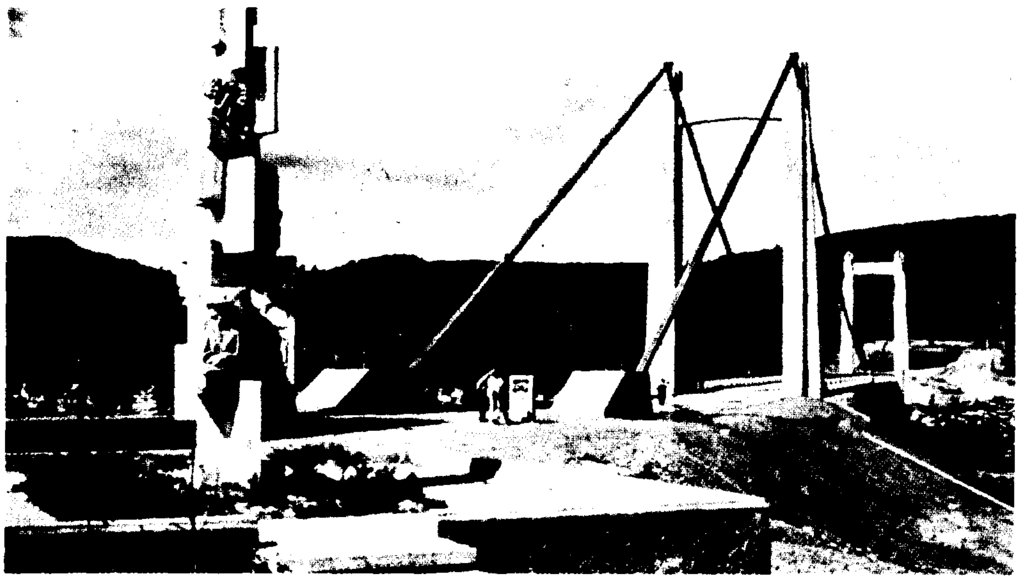

Figure A-21 — Hudson Hope Suspension Bridge, British Columbia

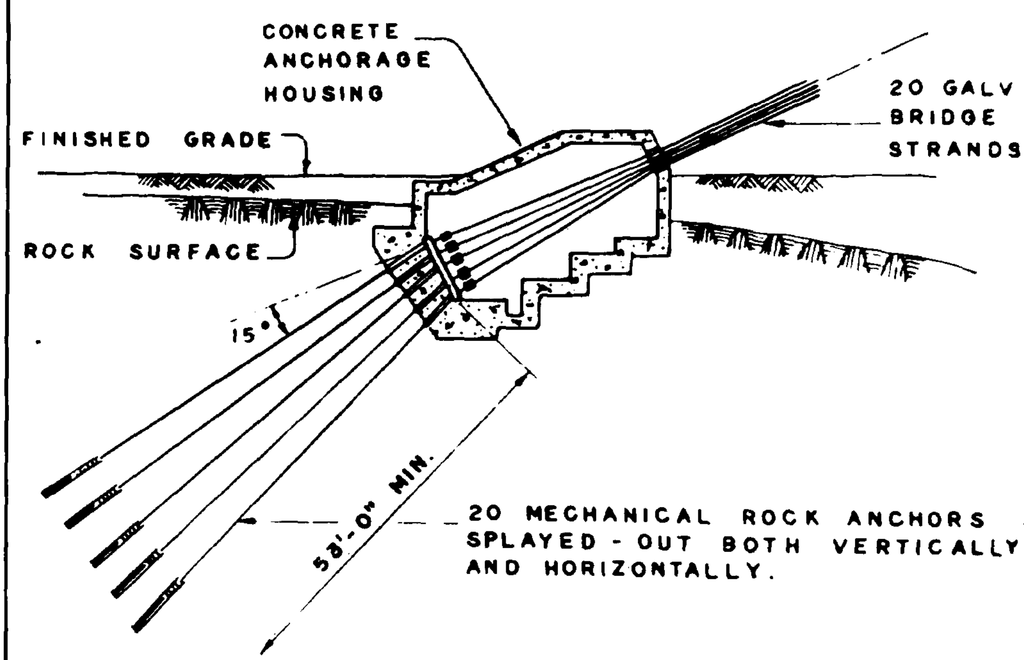

Figure A-22 — Prestressed suspension cable anchorages, Hudson Hope Suspension Bridge, British Columbia

Figure A-23 – Pine Valley Creek Bridge, California